Experimental and Theoretical Studies of Ice-Albedo Feedback Processes in the Arctic Basin

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LONG TERM GOALS

The overall goal of our proposed work is to develop a quantitative understanding of the processes that collectively make up the ice-albedo feedback mechanism.

OBJECTIVES

To achieve this goal, we must first determine how shortwave radiation is distributed within the ice-ocean system, then assess the effects of this distribution on the regional heat and mass balance of the ice pack. Specifically we wish to determine:

- How is shortwave radiation partitioned between reflection, surface melting, internal heat storage, and transmission to the ocean, and
- How is this partitioning affected by the physical properties of the ice, snow cover, melt ponds and the distribution of particulates?
- What is the areal distribution of ice, ponds, and leads,
- How does this distribution vary with time, and
- What is the impact on area-averaged heat and mass fluxes?
- What are the crucial variables needed to characterize ice-albedo feedback processes and their effect on the heat and mass balance of the ice pack, and
- How accurately can the ice-albedo feedback processes be treated through simplified models and parameterizations?

APPROACH

These objectives are being addressed through a combination of field observations and theoretical modeling. The field observations were directed towards acquiring a complete time series of ice mass balance and optical properties over an entire annual cycle. Particular attention was paid to the spring and summer when changes in ice conditions and ice optical properties are rapid and the impact of the ice-albedo feedback is the greatest. One of our objectives is to apply information obtained from local process and time evolution studies to the estimation of areally-integrated heat and mass fluxes. For this purpose, numerous surveys were conducted to give us a statistical picture of the spatial variability

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 1999		**00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE
Experimental and Theoretical Studies of Ice-Albedo Feedback Processes in the Arctic Basin

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Cold Regions Research and Engineering Laboratory,72 Lyme Road,Hanover,NH,03755

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR’S ACRONYM(S)

11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

within individual ice types, and provide quantitative information on the fractional area covered by these categories within the SHEBA region.

Process-oriented modeling will supplement and augment the field studies. Field data on ice structure and optical properties will be combined with laboratory data to develop and verify a model that relates structural and optical properties in warm sea ice. Such a model is needed in any advanced treatment of radiative transfer in sea ice and will form the basis for modeling efforts to predict the optical evolution of the ice cover during the summer melt season. We will also carry out a theoretical investigation of how reduced ice growth beneath melt ponds affects their impact on the regional mass balance. Other models will be used to generalize observational results on lateral melting and floe size distribution, and to evaluate possible effects of soot released from the ship on albedos, melting and heat fluxes.

WORK COMPLETED

During the past year we completed the SHEBA field experiment, reduced the measurements made during the experiment, and began analysis of the data. The data reduced included measurements of albedo, ice mass balance, ice temperature, melt pond properties, and snow properties. We also created an image library of over 3000 aerial photographs that were taken on 14 helicopter survey flights made during SHEBA. We have disseminated the results of our field studies in a number of ways. Reduced data have been submitted to the JOSS archive. We have also produced a CD-ROM, “SHEBA: Snow and ice studies” with the data and metadata from the field studies.

RESULTS

We are continuing to reduce and analyze data from the year-long SHEBA field experiment. The data include a) observations of the temporal evolution and spatial variability of albedo; b) the ice mass balance at 120 thickness gauges; c) surface-based surveys sampling snow depth and properties in winter and melt pond depth and area in summer; and d) weekly helicopter surveys examining larger-scale variations in ice concentration, melt pond fraction, floe size distribution, floe perimeter, surface temperature, and surface reflectivity (Figure 1). Significant findings to date include:

1. Changes in albedo are a combination of a gradual evolution due to seasonal transitions and abrupt shifts caused by synoptic weather events. There were five distinct phases in the seasonal evolution of albedo: dry snow, melting snow, pond formation, pond evolution, and fall freezeup.
2. Data from more than 100 ice thickness gauges installed in a wide variety of ice types indicated a net thinning of the ice at every multiyear site. Maximum surface melting was in June and July, while bottom ablation peaked in August. Combining results from the sites we found an average winter growth of 0.5 m and a summer melt of 1.05 m that consisted of 0.55 m of surface melt and 0.5 m of bottom melt.
3. Snow cover depth and properties were highly variable. In spring the mean snow depth was 33.7 cm, with a standard deviation of 19.3 cm. The mean snow density was 0.32 g cm-3 and the mean water equivalent was 10.3 cm.
4. Snow surveys showed a gradual increase in snow depth during the winter followed by a rapid 2-3 week snow melt period in early June.
5. Melt pond depth and area fraction increased during summer melt.

6. The seasonal evolution of ice temperature followed a pattern of a cold front propagating down through the ice in the fall, cold ice temperatures and ice growth in late fall, winter and early spring, and warming to the freezing point in the summer (Figure 2). Within this general pattern, there was considerable spatial variability in the temperature profiles, particularly during winter. For example, snow-ice interface temperatures varied by more than 20^{o}C between sites.
7. Thermal deterioration of the ice cover plays a significant role in the summer breakup of the ice pack.
8. In summer ice dynamics affects the surface heat budget of the ice by enhancing ice-ocean heat transfer and by increasing the amount of open water and floe perimeter.
9. Light transmission observations indicated that leads were windows to the ocean and melt ponds were skylights.

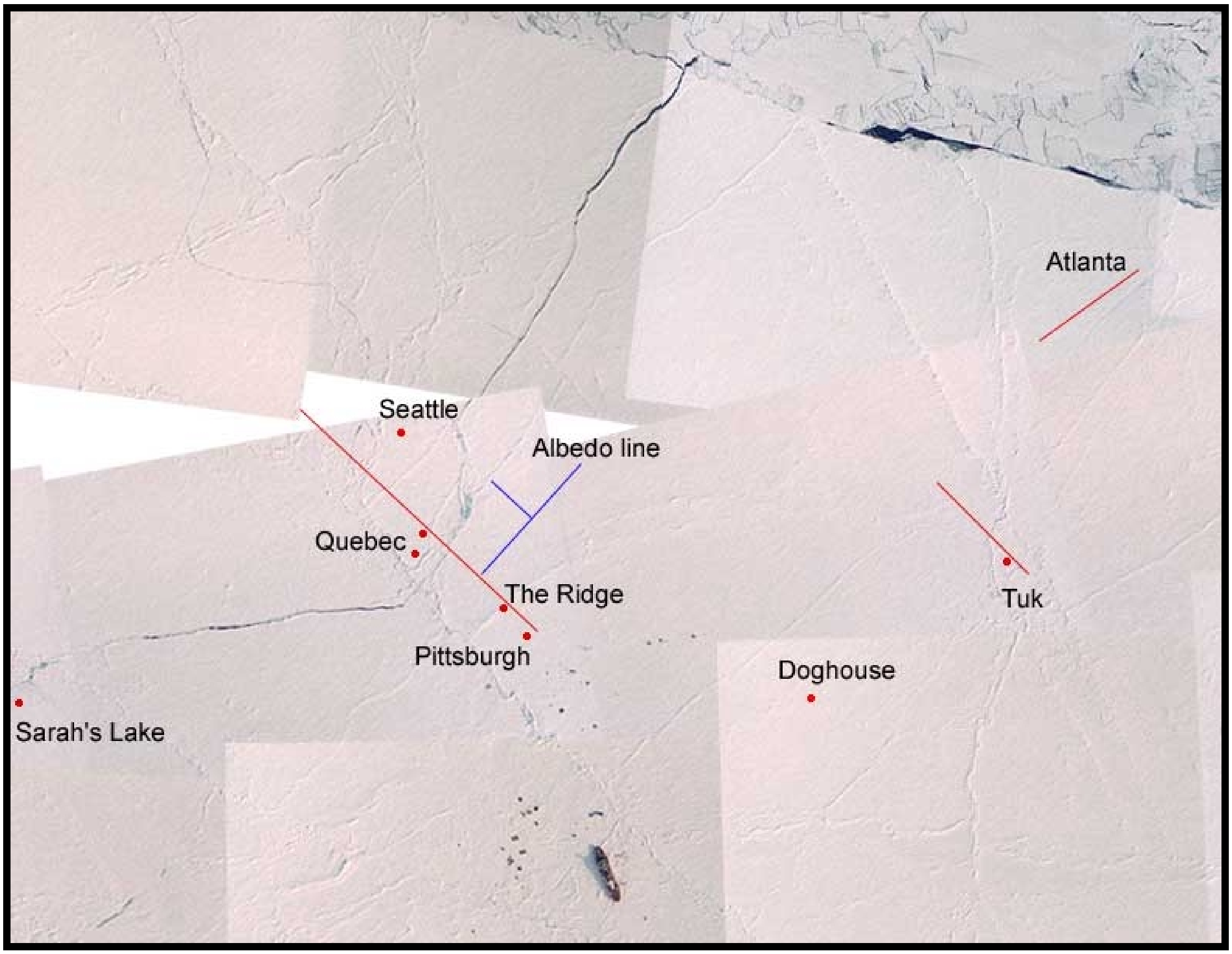

Figure 1. Ice Station SHEBA May 1998. Red dots denote mass balance sites, red lines are snow survey lines, and blue lines are albedo survey lines.

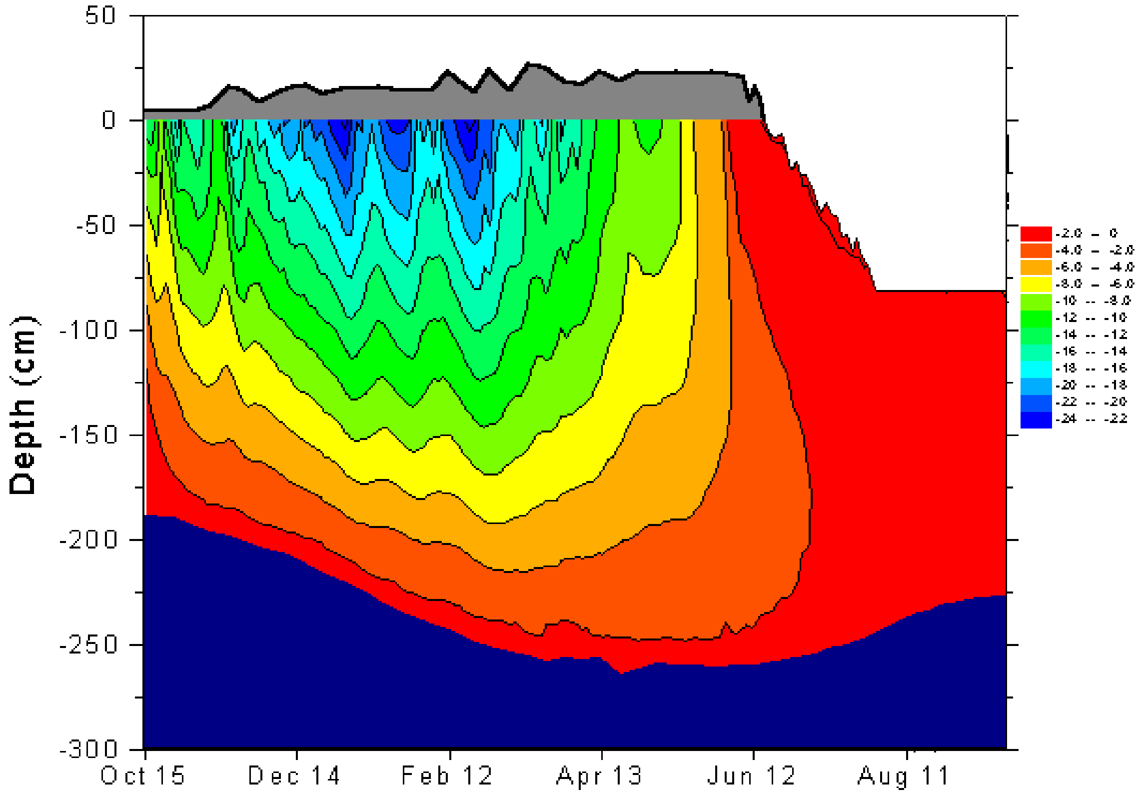

Figure 2. The annual cycle of temperature and mass balance for undeformed multi-year ice in the SHEBA column. The snow cover is gray, the ocean is dark blue, and the colors denote isotherms in the ice. This site increased in thickness from 1.8 m to 2.5 m during winter and had 0.7 m of surface melt and 0.3 m of bottom melt during summer.

IMPACT / APPLICATIONS

Results from this work will help improve sea ice models used for ice forecasting and general circulation models used in climate studies. In particular, more accurate, quantitative parameterizations of the ice-albedo feedback and of the ice mass balance will result from these studies

TRANSITIONS

Data from the year-long field experiment have been reduced and are currently being analyzed in detail. The reduced data are archived on the JOSS catalog and are being disseminated on a CD-ROM entitled "SHEBAICE: Snow and ice studies. Results have been presented an EOS article and in more than a dozen presentations at eight conferences during the past year. Our data are being used by atmosphere and ocean researchers, and have been incorporated into the SHEBA column dataset. The modeling community is making use of our albedo and mass balance observations.

RELATED PROJECTS

This work on this program is being performed jointly with G.A. Maykut and T.C. Grenfell. We are also collaborating with other SHEBA investigators, such as Eicken's studies of ice thickness and permeability; Paulson and Pegau's work on summer leads; McPhee and Morison's upper ocean studies; and the atmospheric boundary layer group's heat flux effort.